Freshwater Aquaculture Geothermal Feasibility Study: Raft River, ID

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Evaluation of the Potential Cascading Use of Waste Geothermal Water for Fresh Water Aquaculture At the Proposed Raft River Power Production Site

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Aquaculture Tank Heating

5-tank heat exchanger	49NT40	AES
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transformer, 115/24v, 40VA	4X746	G

Ventilation Air Heating

Hot water coil, 2 row, 8FPI, 24”x48”		
Heat exchanger, brazed plate,		
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Fan, propeller, 30” 1/2hp	7CC20	G
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Wall shutter	1CO55	G

Note: All equipment should be verified for suitability and compliance with final system design and all applicable codes.

AES – Aquaic Eco Systems www.aquaticeco.com
G – W W Grainger – www.grainger.com

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1.0 Introduction

The Idaho Redclaw LLC facility will be located adjacent to the new US Geothermal Inc. 10 megawatt power plant currently under development near Malta, Idaho. The operation will raise Australian Redclaw crayfish (also known as freshwater lobsters) in indoor tanks with waste heat from the power plant as the source of heat. Initially, the aquaculture facility will use an existing well until the power plant is in full operation. Power plant waste heat is expected to be available at a temperature of approximately 150 F and the temporary source at approximately 240 F though neither of these temperatures has been fully confirmed. This report examines the means by which heat will be delivered to the culture tanks and selected equipment related issues associated with the heating system.

The initial phase of the Redclaw facility, on which this report focuses, will consist of 25 eight foot diameter tanks located in a 2500 square foot steel building. Given the start-up nature of the business, every effort has been made in the identification of example mechanical equipment to select options that are readily available from standard vendors (industrial and aquaculture), and that minimize capital cost and reduce system complexity.

Ultimately waste heat from the operating power plant will be the source for the aquaculture project. Although the temporary source is direct connection to a nearby well of higher temperature, the aquaculture heating equipment described below has been specifically selected for temperatures reflective of those available from the permanent waste heat source. As a result the equipment described would be suitable for that source as well though actual heating loads may cause equipment size and capacity changes.

In terms of project development, land issues and water rights, US Geothermal Inc. and Idaho Redclaw constitute the only major stakeholders in the project. The use of geothermal heat for the raising of agriculture and aquaculture products is a well established technology and widely practiced in the Western US. This particular project involves no special issues that would prevent a successful application using the power plant waste heat. Isolating the aquaculture process from the waste heat stream with a heat exchanger such that only heat is removed, eliminates any chemical changes to the waste stream that might impact disposal of the water. This report addresses only the heat related water needs of the aquaculture process. Although the temporary heat source is an existing well, no additional geothermal water use is expected. Currently this well, a future power plant production well, is produced at a very small flow rate for maintenance purposes. The aquaculture flow requirement falls within this same flow range – thus allowing the existing maintenance flow to be “cascaded” to the aquaculture use.

Late in the process of preparing this feasibility study an alternate enclosure arrangement was developed by the Idaho Redclaw. As a result of this, a section (section 7.0) was added to the end of this report addressing the changes that the alternate enclosure approach would involve relative to the system discussed in the first portion of this report.

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2.0 Geothermal Resource

The initial phase of the aquaculture development will begin operation prior to the completion of the US Geothermal Inc. power plant. As a result, waste water from the plant will not be available and an alternate source will be used. This will consist of water supplied from a nearby future production well for which piping is already in place to the steel building housing the Redclaw facility. Prior to the initiation of this study, this particular well was chosen by US Geothermal Inc for temporary aquaculture use due to its proximity to the steel building and the need to "bleed" a small flow from the maintenance purposes. The demand of the temporary aquaculture use is below this bleed flow rate so no additional geothermal water use would be associated with the aquaculture operation. As a result no additional evaluation of other wells for the aquaculture operation was necessary. The exact temperature of the water available from this well is not known but it is expected to be approximately 240 F and under a pressure of approximately 175 psi according to US Geothermal Inc. The temperature, pressure and possibly chemistry of this source are unsuitable for use in the small heat exchangers recommended for heat transfer to the aquaculture water. As a result an intermediate heat exchange must take place between the geothermal water and the aquaculture main heating loop. In fact some type of heat exchange will also be likely once the aquaculture system is operating on plant waste heat as well. Isolation from the heat source eliminates the potential for contaminating the geothermal water (on its way to injection) with fish waste, eliminates any geothermal water chemistry issues for the fish, and isolates the small aquaculture equipment from the higher pressures of the waste heat stream. A plate type heat exchanger would be the most suitable isolation device for this duty.

A simple approach to this, suggested by Kevin Kitz of US Geothermal Inc., would consist of using the existing 6 inch steel pipeline from the well to the building as a heat exchanger. Based on the heating load of the first phase of the Redclaw facility, the flow requirement from the well could be handled by a line as small as 2 inches. As a result the existing line is much larger than required. If a smaller pipe of 3 inches in diameter were placed inside the existing 6 inch line, the water from the aquaculture facility could be passed through smaller inside line while the hotter, high pressure water from the well flows in the opposite direction in the annular space between the outside of the 3 inch pipe and the inside of the 6 inch pipe. This configuration would form what is referred to as a concentric pipe heat exchanger. Although this type of heat exchanger is typically very low performance in terms of heat transfer, due to the capacity of the resource (substantially in excess of the heating load) and the need for only temporary service, its use here is appropriate. According to US Geothermal Inc., ordinary carbon steel will provide acceptable service in the expected geothermal fluid chemistry.

Based on the calculated peak load of 725,000 Btu/hr (discussed in detail in the heating requirements section), with water entering at 130 F and leaving at 150 F on the secondary side and water entering at 240 F at a flow of 18.1 gpm on the primary side, a length of 180 ft. would be required for the heat exchanger. The existing pipe line is approximately

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200 ft. in length according to US Geothermal Inc, which is sufficient length to accommodate the installation.

In order to achieve counterflow in the heat exchanger, the cold (130 F) secondary water would have to enter nearest the building and the heated secondary water exit at the far end of the heat exchanger. As a result the heat loss in the line carrying the heated water back to the steel building could be an issue. At a flow rate of 63 gpm, using 2 ½ inch Chlorinated Polyvinyl Chloride (CPVC) pipe, with an entering water temperature of 150 F, a burial depth of 42 inches and an assumed soil thermal conductivity of 1.0 Btu/ hr ft F, the heat loss from the line is approximately 115 Btu/hr LF. This results in a temperature loss in the line (after reaching steady state conditions) of only 1 F. The low loss arises from the very low thermal conductivity of CPVC and the high flow rate in the line. Temperature control for the heat exchanger could be accomplished either on the primary side (with throttling of the geothermal flow) or secondary side with partial bypass from the return line at off peak conditions.

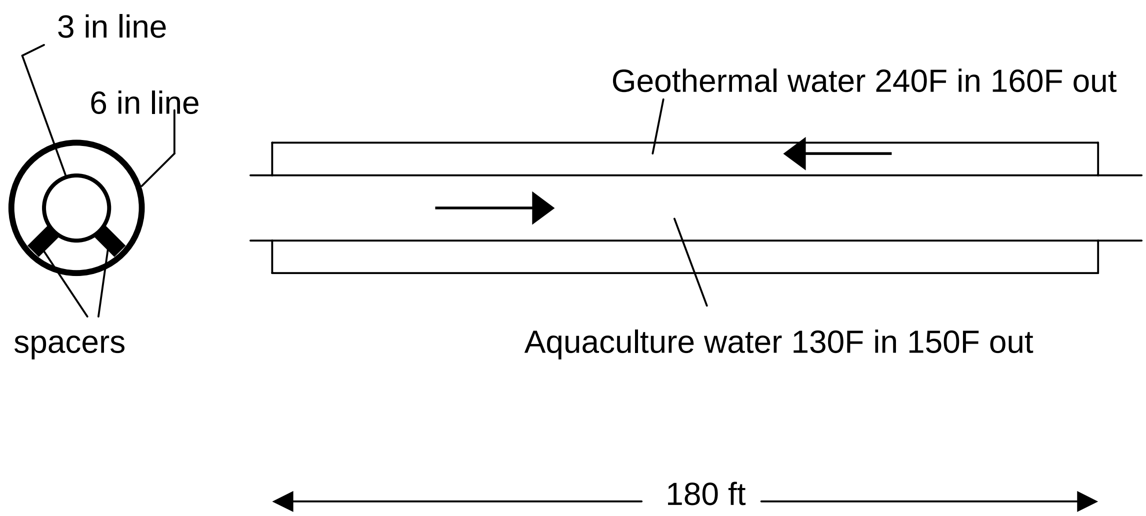

Figure 1
Geothermal to Heating Loop Heat Exchange

Though this fabricated heat exchanger is practical for the initial phase of the project, it is likely that as the facility is expanded commercial plate and frame type heat exchanger will be a more effective solution.

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3.0 Initial Facility Layout

This report is based on the facility layout as it appears in Figure 2. The 25 tanks are arranged in 5 groups of 5 tanks each. Each of the groups of tanks is designed to function as an individual culture system complete with its own dedicated water circulation system, biofilter and heating equipment. The separation of the 25 tanks into distinct subsystems is typical of commercial aquaculture design. It allows for individualized culture, feeding and temperature control and facilitates isolation in the event of disease.

The building in which this initial phase will be located is an existing insulated steel building left from the original Department of Energy project at Raft River. It is expected that subsequent expansion of Redclaw will take place in greenhouse type structures and may employ different size tanks and related equipment.

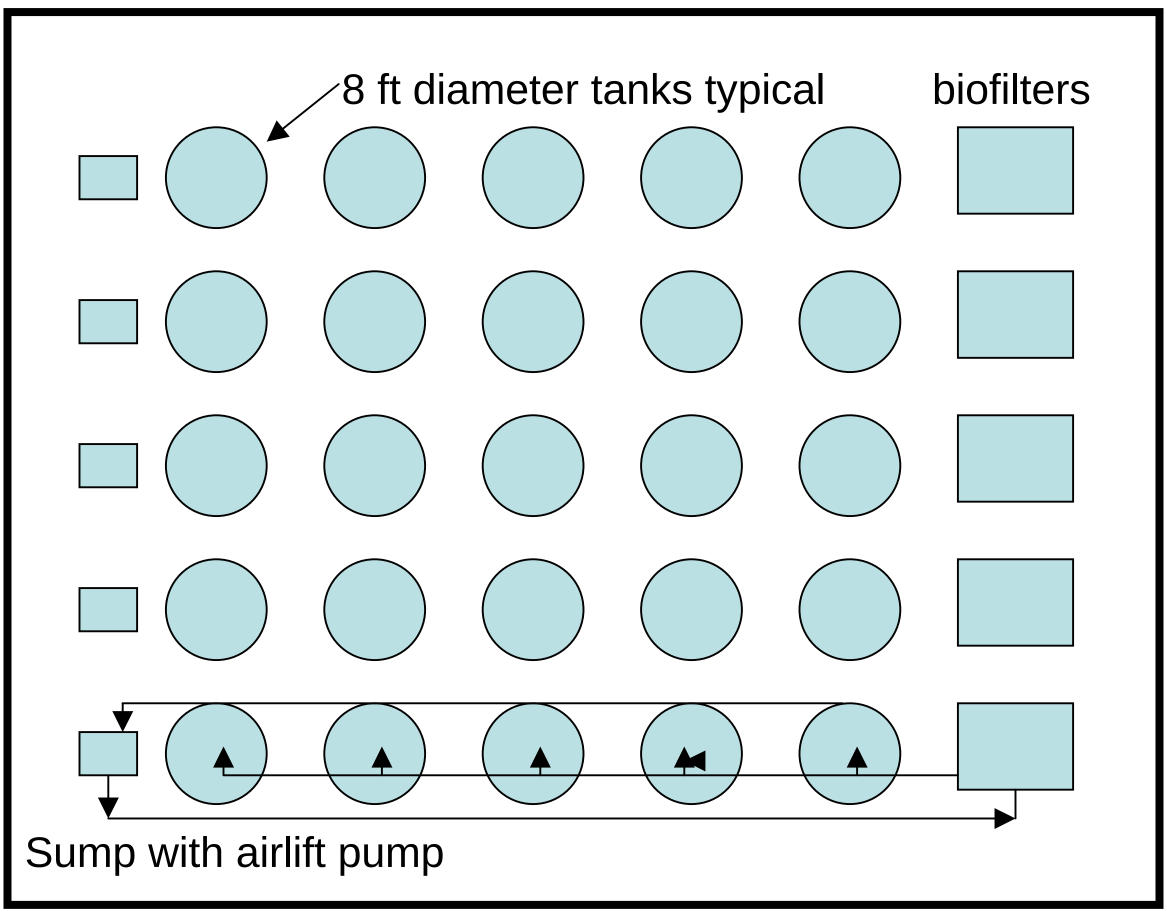

Figure 2
Layout of initial Phase of Redclaw Aquaculture Facility

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Each tank will be equipped with a standpipe to control water level. The standpipes will discharge to a common collection line that delivers the water to a sump located at the end each group of tanks. Water from the sump will be delivered to the biofilter by an airlift arrangement with the biofilter located sufficiently above the level of the tanks to facilitate return flow by gravity from the biofilter to the culture tanks. Figure 2 indicates simplified flow scheme for illustration. Actual piping and component location will likely vary from the arrangement shown.

The tanks will be maintained at a temperature of 85 F, optimum for culture of Redclaw. Water circulation rate will be approximately 1 change of tank volume per hour. For the size tanks planned, this amounts to a flow rate of 66 gpm per 5 tank circuit or about 13.2 gpm per tank.

4.0 Heating Requirements

Heating requirements for the facility resolve themselves into three general areas:

- Aquaculture process (tanks and biofilters)
- Ventilation
- Building space heating

The focus of this report is the Aquaculture process loads. Some discussion of the remaining loads is provided to place the process loads in context and as a result of the fact that all loads are somewhat interdependent.

4.1 Aquaculture Process Loads

According to Redclaw LLC, 8 foot diameter tanks will be used for the first phase of the development with water in the tanks maintained at a temperature of 85 F. The heat loss of the tanks is dependant upon the temperature of the water and the temperature and humidity of the air in the building.

Table 1 provides a breakdown of the losses by type. As in the case of most open bodies of water exposed to the air, evaporative losses constitute the largest single mode of loss.

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Table 1
Aquaculture Tank Heat Loss Summary
(60 F air, 60% RH, 85 F water)

Water surface		
	Evaporation	5982 Btu/hr
	Convection	1279
	Radiation	1472
Wall losses		
	Convection	1279
	Radiation	1472
Floor loss		
	Conduction	500
Total		11,984 Btu/hr

The loss calculated at 60 F inside air temperature is reflective of what would occur in the case of starting the process up in cold weather. The inside air temperature under most normal operating conditions would exceed the 60 F value.

Assuming that the biofilter (an open tank of rectangular configuration with exposed media for bacterial growth) approximates a 6th tank in each circuit, the total heat loss from the tanks would amount to 72,000 Btu/hr for each circuit. It is unlikely that insulated piping will be used in this project and as a result some heat loss from the piping will occur in each circuit. Since the final layout is not known at this point it is prudent to add 10% to the calculated load to account for potential pipe and other losses. This would result in total heat exchanger load of 72,000 + 7200 = 79,200 Btu/hr per circuit provided a central heat exchanger serving 5 tanks is used. Individual tank heat exchangers could be sized for the actual tank heat loss (12,000 Btu/hr) since the length of pipe involved in individual heat exchangers would be negligible.

4.2 Ventilation Air Load

Recommended practice for structures housing indoor pools, spas, fountains or other substantial moisture producing sources is to maintain a relative humidity in the space of 60% or less. This minimizes potential mold, mildew and structural problems arising from high moisture condensation. There are many ways of achieving this goal including mechanical dehumidification, use of covers to reduce evaporation and ventilation/exhaust. Generally covers are not a practical approach in commercial aquaculture and mechanical dehumidification is capital and operating cost intensive. Ventilation consists of passing large amounts of outside air though the building to carry away the moisture generated by the open water. One of the major drawbacks to this is that in cold climates, the cost associated with heating the ventilation air prior to

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introducing it to the space. In this case, the availability of the geothermal source for heating renders the ventilation strategy of humidity control a more practical one.

The amount of ventilation air required (in cubic feet per minute or cfm) is a function of the quantity of moisture to be removed, the moisture content of the outside air and the relative humidity level in the space. In this application the tanks will generate approximately 4 pounds of evaporated moisture per tank per hour under average operating conditions. At a temperature of 0 F outside, the relative moisture contents of the inside air (at 70 F and 60% RH) and the outside air are such that approximately 4500 cfm of exhaust air is required to remove the moisture from the building. Higher air flows are required at higher outdoor temperatures but the heating requirements for the air reach a maximum at the minimum outside temperature. One arrangement for the ventilation would consist of an exhaust fan at one end of the building exhausting this flow of air, and an opening at the opposite end of the building to admit the ventilation air. A hot water coil placed at this opening could heat the air to approximately 60 F prior to its entry to the space. This approach would place the building under a slightly negative pressure – the recommended strategy in this case. A negatively pressurized building causes any leaks in the building to experience a flow of air from outside to inside. In a building with high indoor humidity in a cold climate this limits the ability of warm moist interior air to drift toward the cold skin of the building where condensation could occur. Positively pressurizing a building under the same conditions promotes condensation. A negatively pressurized building has implications for the building envelope as well. In order to protect the insulation from moisture damage and to reduce the leakage of outside air into the building, it will be necessary to install a full, well sealed vapor barrier on the walls and ceiling. As most steel buildings are relatively leaky structures, the vapor barrier will help to assure that most of the air is drawn into the building through the pre-heat coil and not though gaps in the structure.

Due to the heat gain from the tanks in the building, under some conditions heating of the ventilation air is not required as the heat from the tanks more than compensates for the cold incoming air. At outside temperatures below approximately 38 F some heating of the ventilation air is required to assure that inside temperature does not drop below 60 F. In fact heating of the ventilation air may be desirable at outside temperature above 38 F to avoid the possibility of cold ventilation air impinging on tanks or occupants. Assuming that the 4500 cfm ventilation rate was heated from zero to 60 F prior to entering the space, this would impose an additional heating load of 239,000 Btu/hr.

It is important to note that the 4500 cfm ventilation rate is appropriate to low outside air temperatures and higher rates will be necessary at some other conditions. Additional ventilation is advisable at outside air temperatures greater than about 65 F to control inside air temperature. The building should be equipped for at least 10,000 cfm of ventilation.

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4.3 Building Space Heating

The heat loss of the building is subject to some uncertainty due to the condition of the existing insulation as it has deteriorated over the years from age, bird and animal damage. Redclaw personnel report that the insulation was originally rated at R15. For purposes of this work a somewhat lower value of R11 has been used to reflect the reduced effectiveness resulting from damage and deterioration.

Based on the R11 value, the total transmission heat loss of the building amounts to 50,000 Btu/hr or about 20 Btu/hr per square foot of floor area assuming an inside temperature of 60 F and an outside temperature of 0 F. In addition to the losses through the walls and floors, buildings also experience a heat loss associated with cold air leaking into the structure. In this case that effect will be somewhat increased due to the impact of the exhaust fan operation. Assuming an infiltration rate of 1.5 changes per hour, this will add 40,000 Btu/hr for a total heating load of 90,000 Btu/hr.

Total system heating requirements for the 3 loads (aquaculture tanks, ventilation and building space heat) amount to 725,000 Btu/hr.

5.0 Heating Equipment Options

5.1 Aquaculture Tank Heating

A question often arises from developers of aquaculture facilities as to whether it is more effective to heat the water in the tanks or just the air in the building to maintain water temperature. Generally, it is good practice to heat the water directly since this is where the animals are grown. Of equal importance, from a practical standpoint, given the temperatures typically employed in aquaculture and the nature of heat loss/gain from the tanks it is impractical to heat only the air in the building to maintain acceptable water temperature. The majority of the heat loss from an open body of water is through evaporation. Even if the air temperature is the same as the water substantial heat loss continues to occur through evaporation. Raising the air temperature to a level sufficient to make up for the evaporation heat loss would result in air temperatures well over 100 F – obviously impractical for workers. As a result though some heating of air (especially ventilation air in cold climates) may be necessary, heating of the water is the primary task.

There are a variety of issues influencing the selection of heating equipment and the design of heating systems for aquaculture facilities. In many cases tanks, ponds and raceways are heated by directly adding geothermal water to the vessels according to heating requirements. In applications where this is not feasible such as this one, some heat exchange equipment must be used to isolate the geothermal fluid from the culture water. Heat transfer to aquaculture water should involve equipment specifically designed for the purpose and in recognition of fouling and contamination issues unique to the

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application. Fouling can be a significant issue particularly in intensive so called “green water” processes. If present, unusually high fouling of heat transfer surfaces impedes heating capacity and can require frequent cleaning to address the condition. The Redclaw operation according to the developer will not employ a green water process and as a result should be less subject to fouling issues. In addition, animal to water densities in this facility are expected to be far below intensive fin fish conditions reducing the generation of waste products. Contamination of the culture water with metals leached from the surfaces of heat exchange equipment is also a danger if materials of construction of equipment in contact with the water are not selected with adequate care. As with most other aquaculture applications, copper is unsuitable due to the contamination issue as is any galvanized material. Ordinary steel and iron are unsuitable due to the high oxygen content and temperature of the water which both greatly accelerate corrosion of these materials. Generally plastics and corrosion resistant materials such as stainless steel and titanium are the preferred materials for use in heat transfer equipment which is in direct contact with the culture water.

The placement of the heat transfer equipment is also a consideration. There are three basic approaches to the placement of the heating equipment in a facility layout similar to Figure 1:

- Individual tank heat exchangers submerged in each tank
- Individual tank heat exchangers attached to the walls of each tank
- Group heat exchangers serving each 5-tank sub-circuit

5.1.1 Submerged Tank Heat Exchangers

Individual submerged heat exchangers in each tank can be configured in at least two ways. Commercially available heat exchangers specifically designed for this service are available. They are typically constructed of titanium tubing with enhanced surfaces for more effective heat transfer. One manufacturer’s product appears in Figure 3. This heat exchanger is capable of delivering 6000 Btu/hr with heating water entering at 140 F. For this application two exchangers would be required per tank.

The primary advantage of heat exchangers similar to those of Figure 3 is their low cost. The list price of these heat exchangers is $8 each. The disadvantage is the placement in the tank with the animals. Surface temperatures potentially injurious to the animals are present along with the negative impact the heat exchangers can have on feeding and tank maintenance. Though protective shields or cages can be placed around the heat exchanger, this can inhibit heat transfer and tank maintenance. Submerged equipment can become a gathering place for waste material and frequent cleaning may be required to maintain capacity. Finally the cost of controls is higher than other alternatives since each tank would require its own temperature controller, control valve and associated wiring, plumbing. The added cost of these components (in excess of $300) would far outweigh the apparent cost advantage of the heat exchangers themselves. It would be possible to control all of the heat exchangers for a group of tanks from a single sensor (thus reducing costs) however the potential for over or under heating individual tanks would be great and this approach is not recommended.

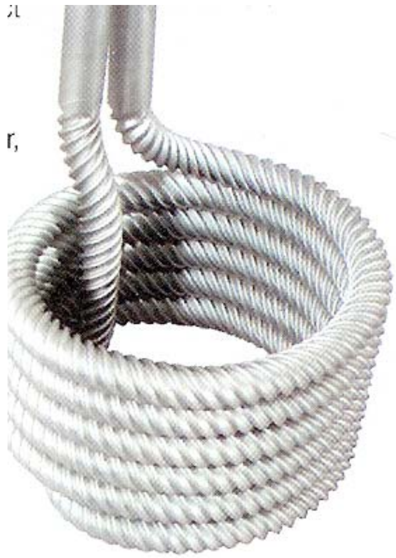

Figure 3
Titanium Tube Submerged Heat Exchanger

An alternate approach to a submerged heat exchanger is to simply submerge an adequate amount of plastic tubing to serve as a heat exchanger. The poor thermal conductivity of plastic tubing however results in a requirement of 100 ft of tubing to meet the required load. Even though the cost of polyethylene tubing is a fraction of titanium tubing, the total cost of the polyethylene heat exchange tubing is approximately twice the titanium heat exchangers described above. The polyethylene approach also suffers the same disadvantages of submerged heat exchangers in terms of the impact on cleaning and maintenance of the tanks. Table 2 provides a summary of costs associated with the two different approaches to tank heating with individual submerged heat exchangers.

Table 2
Estimated Cost for Submerged Tank Heat Exchanger (equipment only)

Heat Exchanger (titanium -2)	$16	(plastic tubing $35)
Electronic temperature controller	85	
Control Valve	100	
Piping (from valve to ht exch)	40	
Manual shut off valves 2	32	
Wiring (control only)	10	
Subtotal	$283	(plastic tubing $302)
Cost for 25 tanks	$7075	(plastic tubing $7550)

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5.1.2 Exterior Surface Heat Exchangers

A second alternative to tank heating is to attach a heat exchanger to the outside of the tank wall and use the tank wall as a heat exchanger. The advantage to this approach is that the heat exchanger no longer resides inside the tank in such a way as to impact the animals or the maintenance of the tank. The simplest version of a wall heat exchanger is to wind flexible plastic tubing around the circumference of the tank and circulate the hot water through the tubing. In this application, assuming the use of ¾" tubing, a 140 F supply water temperature and a 115 F return temperature, a total of 730 ft of tubing would be required. This would cover the outside of the tank from the floor to a height of 24 inches. Again one of the disadvantages is the requirement for individual controls on each tank to avoid the temperature variation that would occur with centralized control of a group of tanks. In addition there are the practical considerations of the necessity of exterior insulation around the tubing on the tank and the difficulty of maintaining good thermal contact between the tubing and the tank. With the high coefficient of thermal expansion in the polyethylene tubing there would be a total of 33 inches of expansion in the 730 feet of tubing when it rises from 85 F to its operating temperature of 128 F creating a great deal of "slack" in the tubing. As a result of these issues the exterior heat exchanger approach is not recommended for this project.

5.1.3 Group Heat Exchangers

The third approach is to supply the heat to the recirculating water between the biofilter and the tanks. This permits the use of single heat exchanger for a group of 5 tanks – an approach that reduces the cost of controls and limits the potential for tank water temperature variation. Although there is only a single point of control for the 5 tanks, the temperature of the water delivered to each tank is the same. Since it is necessary to maintain equal water flow to all tanks for other culture reasons (water quality), temperature excursions are unlikely to occur. If the heat exchanger is placed down stream of the biofilter, fouling will be minimized as this is the highest quality in the system. Figure 4 provides a simplified diagram of the heat exchanger location and flows relative to the general culture layout.

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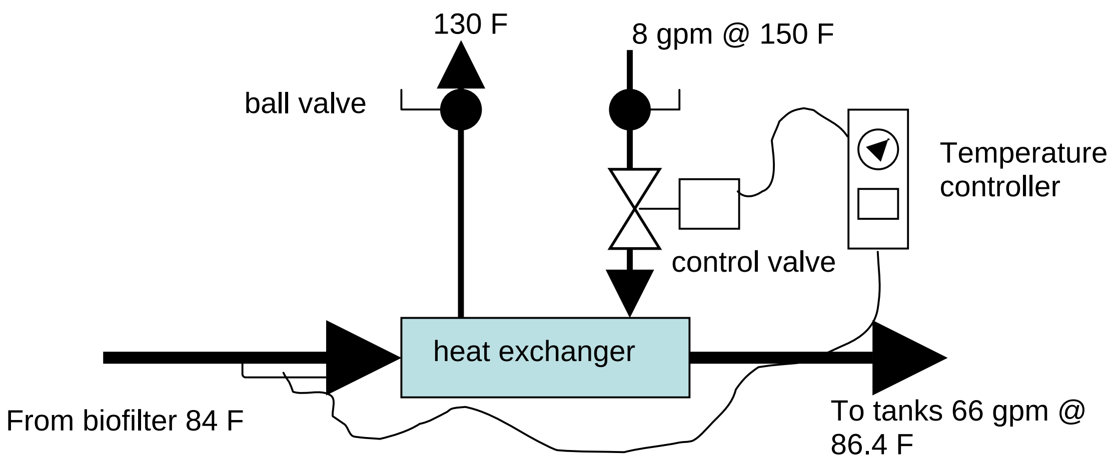

Figure 4
Five Tank Central Heat Exchanger Flow Scheme

A commercially available heat exchanger is well suited to this application. This piece of equipment designated a Heat Line model 49NT40 has a rated capacity of 136,520 Btu/hr with an entering water temperature of 194 F and a secondary (tank side) flow of 66 gpm. In this application with maximum entering water temperature 150 F, the capacity would be reduced to approximately 79,500 Btu/hr – a value equal to the calculated design heat loss of each 5-tank/biofilter circuit. The heat exchanger has a head loss (pressure drop) of 2.6 feet on the tank side. As a result the planned pumping arrangement serving the tanks will have to be capable of providing this additional pressure drop either through additional pump head for the circulating pump or additional elevation of the biofilter above the tanks. The heat exchanger is constructed of a combination of plastic and titanium so as to be relatively inert to exposure to culture water and not pose a threat of contamination due to leached metals.

Table 3 provides a summary of the estimated costs associated with this approach for tank heating. Although the list price of the Heat Line exchanger ($435) is substantially higher than the individual submerged heat exchangers, the reduced number of units required in conjunction with the reduced number of temperature controllers and related hardware results in a lower cost for this design.

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Table 3
Estimated Cost for 5-Tank Central Heat Exchanger (equipment only)

Heat Exchanger	$435
Electronic temperature controller	85
Control Valve	100
Piping (from valve to ht exch)	40
Manual shut off valves 2	32
Wiring (control only)	10
Subtotal	$702
Cost for 25 tanks (5 units)	$3510

The reduced capital cost, reduced equipment requirements, reduced controls and related equipment issues clearly identify this approach as the preferred choice from an engineering standpoint.

5.2 Ventilation Heating Equipment

Heating of ventilation air is normally accomplished by passing the outside air though a custom designed hot water coil equipped with automatic controls to maintain a constant leaving air temperature. Outside air heating coils in climates that have the potential for below-freezing entering air temperatures, steam is used as the heating medium or an antifreeze filled loop separate from the main heating system is employed to avoid freezing.

For this application the ventilation heating system could be somewhat reduced in cost if it is simply designed to operate at full capacity at outside temperatures of less than 40 F. Figure 5 presents a flow scheme for the ventilation air heating system.

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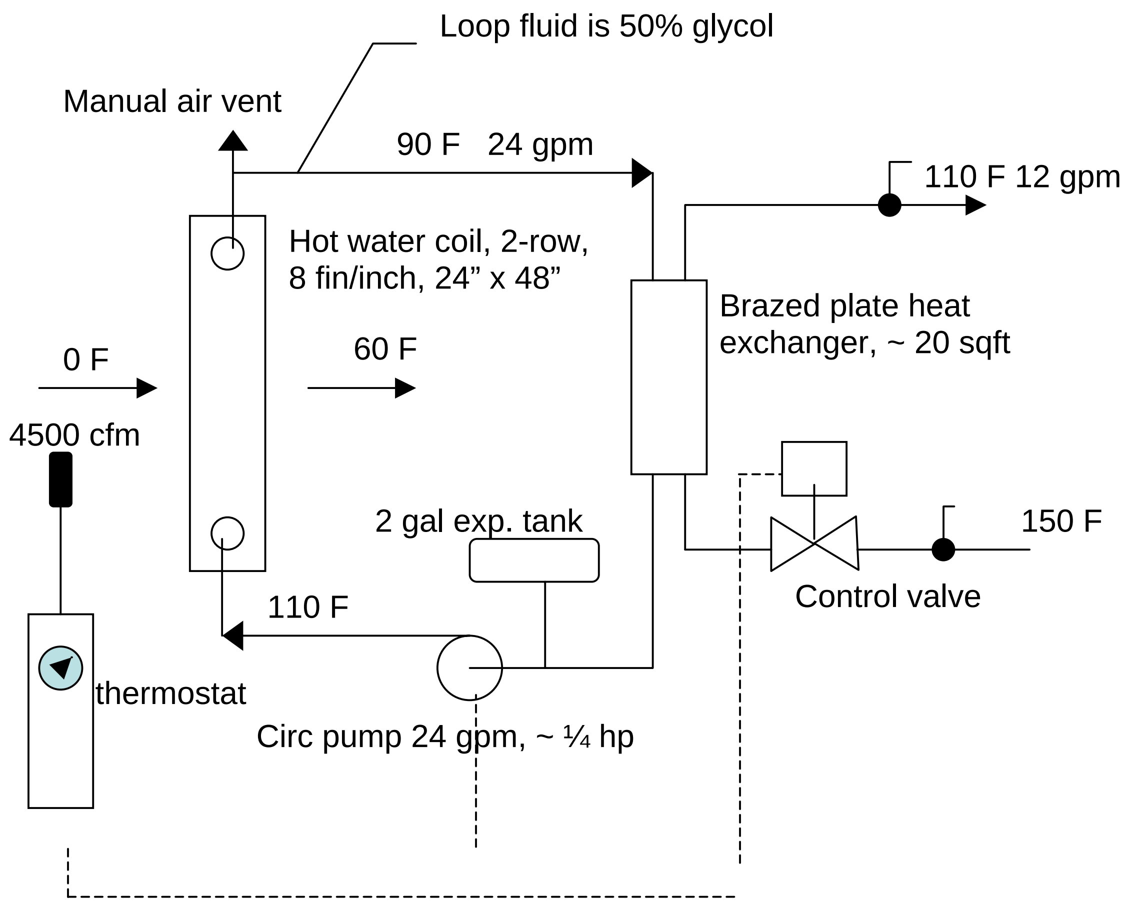

Figure 5
Ventilation Air Heating Flow Scheme

To reduce the potential for freezing, the coil circuit should be filled with a 50% glycol/50% water mixture. Table 4 provides a cost summary of the components required for the ventilation air heating subsystem.

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Table 4
Ventilation Air Heating Equipment Cost Summary
(equipment only)

Coil (2-row, 8FPI, 24 x 48")	$600
Heat exchanger	700
Control valve	120
Thermostat/wiring/pump relay	125
Circulating pump	620
Expansion tank	50
Air vent	8
Pipe/fittings 2" CPVC	280
Pipe/fittings 1 ½" CPVC	200
Shut off valves (ball type)	38
Exhaust fan ½ hp, 30"	760
Total	$3481

5.3 Building Space Heating

The building space heating load can be handled by new space heating equipment or the existing bare pipe perimeter system. If new heating equipment is installed, unit heaters would be the most cost effective solution. In a building of this size, it would be good practice to use at least 4 units located at the corners of the building and oriented in such a way as to promote a circular movement of air around the circumference of the building. However due to the very low use of the space heating system (due to the heating effect of the tanks) and the low occupant density, a system consisting of only two units seems appropriate.

Based on the heating load (transmission + infiltration), each unit would have a capacity of 45,000 Btu/hr. At the available 150 F supply water temperature, unit heaters with a nominal 80,000 Btu/h capacity (@ 200 F water, 60 F air) would be selected. Table 5 presents a cost summary for the 2-unit heaters.

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Table 5
Building Space Heating Unit Heater Cost Summary
(equipment only)

Unit heater (nominal 80,000 Btu/hr)	$607
Zone valve	90
Thermostat/wire/relay	90
1" CPVC pipe (30 ft w/fittings allowance)	90
ball vlaves (2 @1")	30
manual air vent	8
Single unit total	$900
Total for 2 units required	$1800

5.4 Combined Heating System

Figure 6 provides a simplified flow scheme for the entire system assuming that all the subsystems discussed above are combined into a single system. The main circulating pump would provide flow through the entire system with a peak flow of 63 gpm. Since the final design is not established, it is not possible to fully specify this pump, however if total pump head is on the order of 40 ft, the motor should be no greater than 1 ½ horsepower.

The closed nature of the main heating loop in Figure 6 would necessitate, in addition to the pump, an expansion tank, air removal scoop, pressure reducing valve and connection to a pressurized water supply. For simplicity these items are omitted from the figure.

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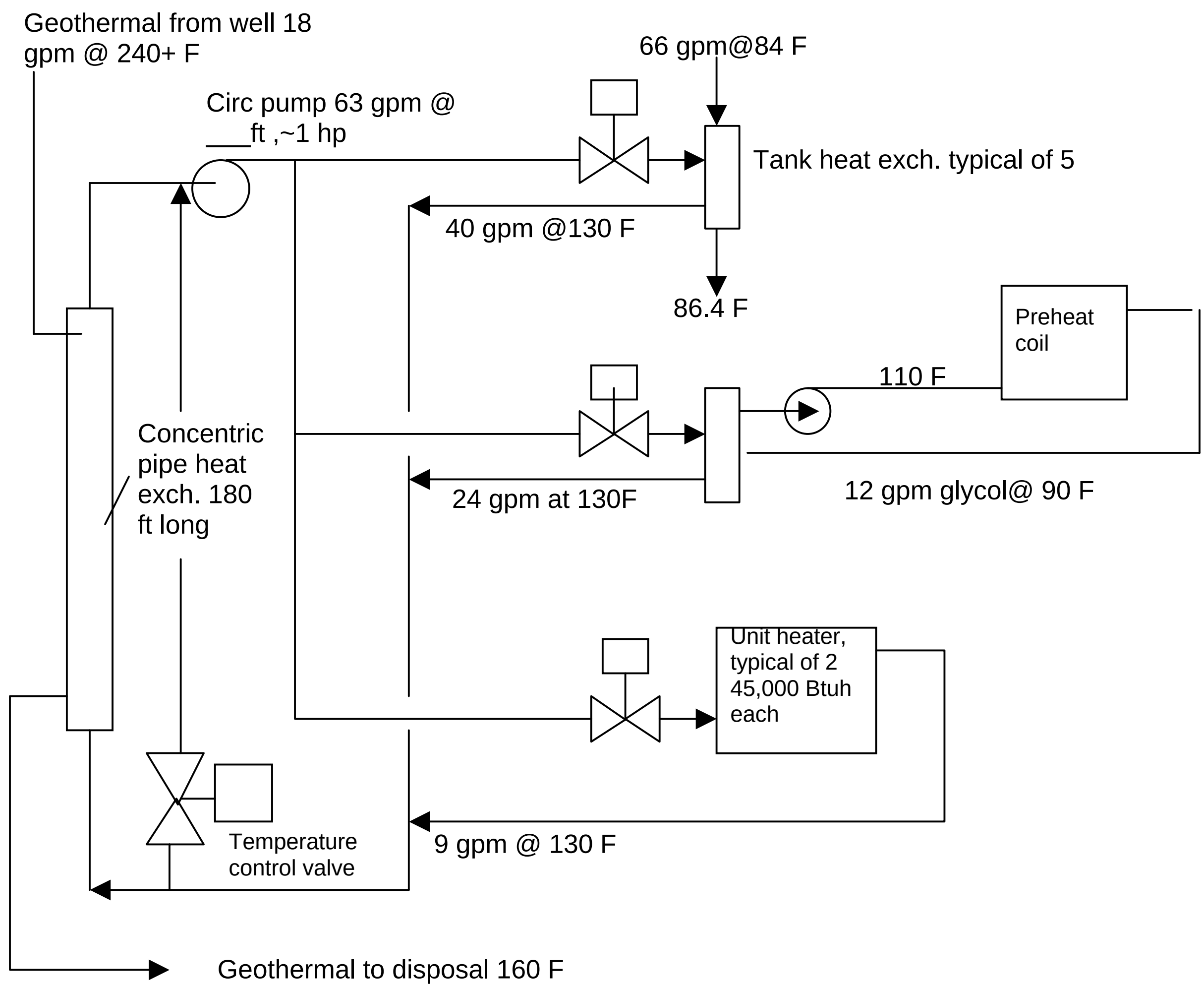

Figure 6
Combined System Flow Scheme

The temperature control valve located parallel to the main geothermal heat exchanger is a self actuated valve that serves to control the supply water temperature to the system by modulating open as the supply temperature rises above the set point. As the valve modulates toward the open position, water is bypassed around the main heat exchanger.

Table 6 presents a summary of the costs for the major components associated with the central heating loop. Piping costs are limited to only that piping associated with the main loop pump. Piping to and from the various heat exchangers, unit heaters and ventilation preheating equipment will depend upon which of those loads are included in the final

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design, how they are arranged within the building and what piping material is chosen for the heating loop. Candidate materials would be CPVC, carbon steel or copper. Of these, CPVC would be the simplest to assemble.

Table 6
Main Loop Hydronic Components – Cost Summary
(equipment only)

Circulating pump 63 gpm, 1.5 hp	$1300
Self powered control valve	300
2 2 1/2" ball valves	180
2 ½" CPVC pipe and fittings	180
Airtrol fitting	26
Pressure reducing valve and ball valve	52
Expansion tank 15 gal	138
Total	$2176

Table 7 presents a summary of the costs associated with the individual subsystems (tank, ventilation, building heating and main loop equipment) discussed in this report. A 20% contingency has been added to each subsystem to account for minor plumbing, electrical and other miscellaneous items not addressed in the major components listed. No cost has been included for the main loop heat exchanger as it is assumed that it can be constructed of scrap materials already on site.

Table 7
System Cost Summary of Major Sub-systems
(equipment only)

Tank heating equipment	$4200
Ventilation air heating equipment	4200
Building heating equipment	2200
Main loop equipment	2600
Total	$13,200

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6.0 Annual Energy Requirements

The annual energy displaced by the use of geothermal in this project is a function of the heating requirements of the building (losses to the outside air), heat gain to the building from the tanks, and the amount of ventilation used to control humidity in the space. It is also influenced by the way the system is controlled. To calculate the annual energy requirement it is necessary to look at all of these simultaneously and to make some assumptions about the way the building will be maintained in terms of the inside air conditions (temperature and humidity). Bin type weather data that provides the number of hours per year at various temperatures along with mean coincident wet bulb temperature is well suited to this type of analysis.

Table 8 summarizes the analysis. Key assumptions were:

- building heating system operated to maintain an inside temperature of 70 F
- 4500 cfm ventilation air
- ventilation preheat operates only below 45 F outside air temperature (OAT)
- tank water maintained at 85 F
- additional ventilation air flow used to reduce inside temperature above 72 F OAT

The annual energy use calculated based upon the above assumptions is approximately 2.1 x 10^9 Btu/yr or 2,100,000,000 Btu/yr. If the facility were heated by a natural gas boiler operating an annual efficiency of 80%, the consumption would amount to 26,250 therms per year.

Bin weather data divides temperature occurrences into 5 F increments or bins. The average temperature for the bin appears in column 1. For example the temperature of 22 F represents all occurrences between 20 and 24 F. Column 2 indicates the number of hours per year, on average, occurring in that temperature bin. Column 3 shows the average temperature inside the building that would result in the particular bin. Column 4 is the total tank heating requirement at the inside temperature appearing in column 3. These calculations were made assuming that the ventilation system maintains an inside humidity of 60%. Column 5 shows the gross building heating requirement for the outside temperature appearing in column 1. Column 6 shows the heat gain to the air in the building from the tanks. This assumes that all of the evaporated moisture is carried from the building by the ventilation air. As a result, this heat gain represents only the radiant and convective heat losses from the tanks. Column 7 shows the temperature of the air leaving the ventilation air pre-heat coil. As noted in the discussion of the ventilation heating earlier in this report, the assumption is that the preheat coil operates at full capacity at all outside temperatures below 45 F. The coil is off above this temperature. This results in the drop in coil discharge temperature (and the corresponding drop in space air temperature) at the 45 to 49 F bin temperature. Column 8 shows the heating load associated with the ventilation air. Column 9 is an intermediate calculation which calculates the heating required to bring the ventilation air to a temperature of 70 F. Column 10 is the capacity required of the building heating system to maintain an inside

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temperature. Column 11 calculates the total heating requirement at each temperature bin which consists of Column 5 + Column 10 + the energy required to heat the ventilation air (4500 cfm) from the outside air temperature to the value appearing in Column 8.

Table 8
Annual Energy Calculation Summary

To	Hrs/yr	Inside Temp F	Tank heat Btu/hr	Bldg Load Btu/hr	Bldg Gain from tanks Btu/hr	Tc	Vent air Load Btuh	70F load Btu/hr	Heating System Btu/hr	Annual Energy Btu/yr x10 6
92	183		80568	0		92	0	0	0	14.7
87	239		104760	0		87	0	0	0	25.0
82	306		126490	0		82	0	0	0	38.7
77	370		126490	0		77	0	0	0	46.8
72	451	85.7	104760	0		72	0	0	0	47.3
67	550	81.8	145152	0	12174	67	0	0	0	79.9
62	638	77.9	171900	0	32879	62	0	0	0	109.6
57	689	73.2	202536	4500	57831	57	0	0	0	139.5
52	762	68	234468	12000	85438	52	0	0	0	178.9
47	803	62.7	265068	19500	113576	47	0	0	0	213.0
42	853	82.9	137448	27000	6334	75	133650	0	0	232.7
37	864	80.7	152820	34500	18014	74	149850	0	0	263.1
32	796	77.7	173232	42000	33941	72	162000	0	0	268.3
27	519	74.8	192312	49500	49337	70	174150	0	0	191.4
22	293	71.8	211320	57000	65264	68	186300	8199	0	117.2
17	152	70	222408	64500	74820	66	198450	16398	6078	65.3
12	79	70	222408	72000	74820	64	210600	24597	21777	36.1
7	41	70	222408	79500	74820	62	222750	32796	37476	19.9
2	25	70	222408	87000	74820	60	234900	40995	53175	12.8
-3	11	70	222408	94500	74820	58	247050	49194	68874	5.9
-8	6	70	222408	102000	74820	56	259200	57393	84573	3.4
-13	2	68	234468	109500	85438	54	271350	65592	89654	1.2
-18	1	65	248400	117000	101365	52	283500	73791	89426	0.6
										2112.0

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7.0 Alternate Building Envelope

In the course of this feasibility analysis, an alternate approach to the building enclosure was suggested. Under this design, the tanks would be located inside a greenhouse-like structure, inside of the steel building. The exact layout and construction of this greenhouse enclosure is not finalized as of this writing. This section evaluates the impact of the new approach relative to the original arrangement with the tanks located inside of the steel building with no secondary enclosure.

The alternate design has the potential to allow greater humidity levels due to the lack of concern about condensation on the steel building components, reduced ventilation air requirements (as a consequence of the higher humidity level), reduced or eliminated ventilation preheat requirements, less concern with air temperatures inside the building. These advantages offer the potential for reduced system cost and complexity in some cases. On the negative side the increased complication and space constraints associated with installing the greenhouse structure inside of the steel building should be carefully considered.

7.1 Tank Heating

Placement of the tanks inside of the greenhouse will reduce the heating requirements as a result of elevated temperature and humidity under the enclosure relative to tanks located in the open building. Based on the assumption of a minimum 50 F air temperature in the steel building (see building heating discussion below), the temperature in the greenhouse enclosure will equilibrate at approximately 72 F. Assuming a humidity level of 90% in the greenhouse, the heating requirement for the 8 ft tanks will be approximately 7600 Btu/hr each. This compares to the approximately 12,000 Btu/hr value for the tanks located in the open steel building. However since the 72F air temperature may not be available at start-up in cold weather the over sized heat exchangers selected for the earlier case would provide a useful safety margin if retained for this design.

The heat exchangers, although oversized for the new load are controlled by differential temperature. The excess capacity would simply result in lower “on” time for the heat exchangers compared to the earlier design.

7.2 Impact of Greenhouse Enclosure

The major impact of the greenhouse enclosure is to reduce heating requirements for the tanks by permitting a higher level of humidity in the enclosure than what would be advisable with the tanks located in the open building. In addition, due to the temperature of the inside surface of the greenhouse cover during colder weather, some of the moisture evaporated from the tank surfaces will condense on the cover thus recovering a portion of the evaporative heat loss. In addition to the reduced heating requirements, the higher humidity level also permits the reduction of ventilation air flow. In the original design,

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the ventilation air flow was 4500 cfm. With the greenhouse approach, assuming that the inside humidity could be raised to 90%, the ventilation air flow is reduced to 1000 cfm. Because the ventilation air would now be drawn from inside the steel building rather than outside, preheating of the ventilation air can be eliminated (assuming that the building space heating system is used to maintain an inside temperature of 50 F in colder weather).

Heat gain from the greenhouse cover to the air inside the steel building, (assuming 25% of the water evaporated from the water surface of the tanks is re-condensed on the greenhouse cover) will maintain the air in the steel building at the 50 F level for all but a few hours per year. The actual rate of condensation on the cover will be driven by a combination of factors including heat loss from the outside surface, steel building air temperature and actual steel building heat loss. In fact the rate of condensation on the greenhouse cover will not be a constant percentage of the evaporated water due to the larger temperature difference between the cover and the greenhouse inside air temperature in cold weather. The assumption of a constant rate for the annual energy calculation should not introduce a significant error since the heating loads decrease at higher outdoor temperatures where the percentage assumption is less valid.

7.3 Building Space Heating

The building heating system remains necessary for emergency use and for heating during start-up in cold weather. The building space heating load remains the same as discussed in the original design and the space heating system should remain as described there. The difference here is that due to the heat gain from the greenhouse cover and the reduced ventilation requirement, the number of hours that the system must operate is substantially reduced. In fact, assuming a 25% re-condensation of the evaporated water on the greenhouse cover, the building heating system would only need to be operated when outdoor temperatures fall below 12 F. This assumes an inside temperature of 50 F in the steel building. This is based on having all of the tanks in operation. If for some reason the aquaculture system was partially or fully shut down in cold weather, the building heating system would be required to operate to a greater extent. The space heating system capacity would remain at 90,000 Btu/hr.

7.4 Ventilation

Although the greenhouse enclosure allows for a greater level of humidity without the structural concerns present in the steel building, it remains necessary to provide a minimum level of ventilation for the enclosure. A rate of 1000 cfm should limit the humidity in colder weather to approximately 90%. The much lower ventilation rate and the fact that the air will be drawn from inside the steel building where the air is generally above 50 F, means that the pre-heating system outlined in the original design can be eliminated. This change reduces the project heating requirement by 240,000 Btu/hr.

Provided a well sealed greenhouse structure is possible, the ventilation air would best be supplied by a blower drawing air from the steel building, forcing it into the greenhouse and out through relief dampers at the opposite end of the house. This arrangement would

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slightly pressurize the greenhouse thus assisting in supporting the cover. A blower capable of providing 1000 cfm at a pressure of 0.3 inches of water gage should be sufficient for this duty.

7.5 Project Heating Load

The total project heating load for the greenhouse design would include the following actual loads:

Tank heating	250,000 Btu/hr
Ventilation	0
Building space heat	90,000
Total	340,000 Btu/hr

As mentioned earlier, the capacity of the tank heating system would remain at the 400,000 Btu/hr value cited in the original design. The difference is that the operating time would be reduced. The same is true of the building space heating system which would operate (under normal circumstances) only at outdoor temperatures of less than 12 F. The peak load on the system of 340,000 is approximately half of the 725,000 Btu/hr load imposed by the original design. The excess capacity in the primary heat exchanger could either be used for system expansion or the size of the heat exchanger reduced proportionally. The reduced heating load would decrease the peak geothermal flow requirement to 8.5 gpm from the original value of 18.1 gpm. The design of the main heat exchanger must consider the reduced water flow so as to avoid laminar flow conditions.

7.6 Equipment Costs

The project costs outlined in Table 7 could be reduced by the elimination of the ventilation air heating system ($4200). A cost of approximately $300 would have to be added to cover the cost of the 1000 cfm ventilation fan and relief damper serving in place of the original ventilation system. In addition, the reduced load would permit the down sizing of some of the main loop components including the pump (now 49 gpm @40ft, 1 hp, $1000), ball valves (now 2” instead of 2 ½”, $50), PVC pipe and fittings (now 2” instead of 2 ½”, $140). This reduces the total cost of the main loop equipment to $1706. Adding the 20% contingency results in a Main loop total of $2200. The new total equipment cost amounts to $8700 compared to the Table 6 value of $13,200.

7.7 Annual Energy Use

The reduced heating and ventilation requirements result in a reduction of approximately 43% in the annual energy use of this arrangement compared to the original design. The details of the annual energy use are presented in Table 9.

Column 1 is the average temperature of the bin for which the calculation is made. Red font indicates below zero temperatures. Column 2 is the number of hours per year

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occurring in that temperature bin. Column 3 is the heating load for the steel building at the inside temperature indicated in Column 4. Column 4 is the calculated inside air temperature in the steel building that would occur at the outside temperature appearing in column 1. This value is the result of the heat balance occurring between the heat lost from the greenhouse to the air in the steel building and the heat lost through the steel building to the outside air. Column 5 is the air temperature that would occur in the greenhouse at the outside temperature appearing in column 1. It is arrived at through the same iterative heat balance described for column4. Column 6 shows the heat gain to the air inside the greenhouse from the tanks. This value assumes that 25% of the evaporative heat lost from the tanks is regained to the air in the greenhouse through condensation of water vapor on the inside surface of the greenhouse cover. Column 7 shows the heating load for the tanks occurring in that particular temperature bin. The heating requirement is calculated at the greenhouse inside temperature appearing in Column 5. Column 8 is the annual tank heating requirement occurring in the temperature bin and is arrived at by multiplying the Column 7 value by the column 2 value. Column 9 is the net heating requirement for the steel building arrived at after deducting the heat gain to the steel building from the greenhouse. It is the amount of heat that would have to be supplied to the space from the heating system (unit heaters). Column 10 is the total annual heating energy required (sum of Column 8 plus column 9). The total annual heating energy requirement appears at the bottom of Column 10 – 1.2 x 10^9 Btu.

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Table 9
Annual Heating Energy Requirement – Double Enclosure

T_o	Hrs/yr	Bldg Load Btu/hr	T_{steel} F	T_{gh} F	Tank Gain Btu/hr	Tank Load Btu/hr	Tank Annual Btu	Bldg annual Btu	Total Annual Btu
92	183	0	92	88.8	-11559	69902	12792118	0	12792118
87	239	0	87	86.8	-678	85649	20470122	0	20470122
82	306	4793	84.5	85.8	4762	93522	28617863	0	28617863
77	370	9968	82.2	84.9	9767	100766	37283397	0	37283397
72	451	14953	79.8	83.9	14990	108324	48854297	0	48854297
67	550	20129	77.5	83.0	19995	115568	63562341	0	63562341
62	638	25112	75.1	82.1	25218	123126	78554604	0	78554604
57	689	30289	72.8	81.1	30223	130370	89824825	0	89824825
52	762	35465	70.5	80.2	35228	137613	104861379	0	104861379
47	803	40449	68.1	79.3	40451	145172	116572958	0	116572958
42	853	45625	65.8	78.4	45456	152415	130010262	0	130010262
37	864	50609	63.4	77.4	50679	159974	138217327	0	138217327
32	796	55210	60.8	76.4	56337	168162	133857011	0	133857011
27	519	60769	58.7	75.5	60907	174776	90708595	0	90708595
22	293	65945	56.4	74.6	65912	182019	53331632	0	53331632
17	152	71121	54.1	73.7	70917	189263	28767935	0	28767935
12	79	76105	51.7	72.7	76140	196821	15548873	0	15548873
7	41	82431	50	72.1	79839	202175	8289178	106271	8395449
2	25	92016	50	72.1	79839	202175	5054377	304424	5358801
3	11	101601	50	72.1	79839	202175	2223926	239382	2463308
8	6	111186	50	72.1	79839	202175	1213050	188082	1401132
13	2	120771	50	72.1	79839	202175	404350	81864	486214
18	1	130356	50	72.1	79839	202175	202175	50517	252692
									1210193135

8.0 Potential Funding Sources

Many potential sources exist for funding start-up aquaculture projects. All have specific criteria for qualification of applicants and must be carefully examined for suitability to this project. Among those that appear to be appropriate are the following:

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- **UNITED STATES DEPARTMENT OF AGRICULTURE (USDA)-RURAL DEVELOPMENT**: USDA Rural Development agency comprises three services: Rural Business-Cooperative Service (RBS), Rural Housing Service (RHS) and Rural Utilities Services (RUS). The field offices at the state and local levels administer the programs. Most relevant to rural agribusiness, is RBS which mission is to build competitive rural businesses and cooperatives. There is also (a) The USDA Rural Development's Business & Industry (B&I) Loan program that had, so far, served aquaculture, nurseries, and forestry businesses, meat processing and distribution projects. (b) The Rural Development's rural Business Enterprise Grant (RBEG) funding had included agribusinesses project. (c) The Rural Development's Intermediary Re-lending Program (subject to RD Instruction 4274-D) provides funding support also. Contact:

208-378-5600
USDA Rural Development Idaho

9713 West Barnes Drive Suite A1
Boise, ID 83709

- **USDA COOPERATIVE STATE RESEARCH, EDUCATION, AND EXTENSION SERVICE (CSREES) GRANT-Western Region Sustainable Agriculture Research and Education (WSARE):** The goal of this subtitle is to encourage the research and education designed to increase our knowledge concerning integrated systems of plant and animal production practices having both a site specific and regional application that will over the long-term improve food sources, the environment, efficient use of renewable resources, enhance economic and social wellness. Contact:

Western SARE Program
Agricultural Science Building, Room 305
Utah State University
4865 Old Main Hill
Logan, Utah 84322-4865
Tel:(435) 797-3537, Fax:(435) 797-3376
Email: wsare@mendel.edu

- **SMALL BUSINESS INNOVATION RESEARCH PROGRAM (SBIR) GRANT**: This program invites science-based small business firms to submit research proposal for funding. Topic areas include Forests and Related Resources, Plant Production and Protection, Animal Production and Protection, Air, Water and Soils, Food science and Nutrition, Rural and Community Development, Rural and Community Development, Aquaculture, Industrial Applications, and Marketing and Trade. Contact:

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Dr. Charles F. Cleland
Director, SBIR Program
Cooperative State Research, Education, and Extension Service
U.S. Department of Agriculture
STOP 2243
1400 Independence Avenue, S.W.
Washington D.C. 20250-2243
Tel: (202) 401-4002, Fax: (202) 401-6070

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Appendix A – Equipment sources

Aquaculture Tank Heating		
5-tank heat exchanger	49NT40	AES
temperature controller, electronic, immersion sensor	6XJ74	G
control valve, hydronic zone, ¾”	2E991	G
transformer, 115/24v, 40VA	4X746	G
Ventilation Air Heating		
Hot water coil, 2 row, 8FPI, 24”x48”		
Heat exchanger, brazed plate,		
Control valve, hydronic zone, ¾”	2E991	G
Thermostat, remote bulb	2E834	G
Relay, transformer, 24V	2E852	G
Circulating pump, 1/4hp	5YN65	G
Expansion tank, 2.1 gal	2P672	G
Air vent, automatic	4A821	G
Building Space Heating		
Unit heaters, hot water, 87,100 Btuh nominal	5YH19	G
Zone valve, ¾”	2E991	G
Thermostat,	5E266	G
Relay/transformer	2E852	G
Main Loop		
Circulating pump, 66 gpm, 1 ½ hp,	5YN73	G
Self powered valve		
Airtrol fitting, 1 ¼”	4UN90	G
Pressure reducing valve	4A822	G
Expansion tank, 20 gal	2P671	G
Ventilation		
Fan, propeller, 30” 1/2hp	7CC20	G
Fan guard	6D586	G
Wall shutter	1CO55	G

Note: All equipment should be verified for suitability and compliance with final system design and all applicable codes.

AES – Aquaic Eco Systems www.aquaticeco.com
G – W W Grainger – www.grainger.com